Prospectives for stop searches at ATLAS and CMS

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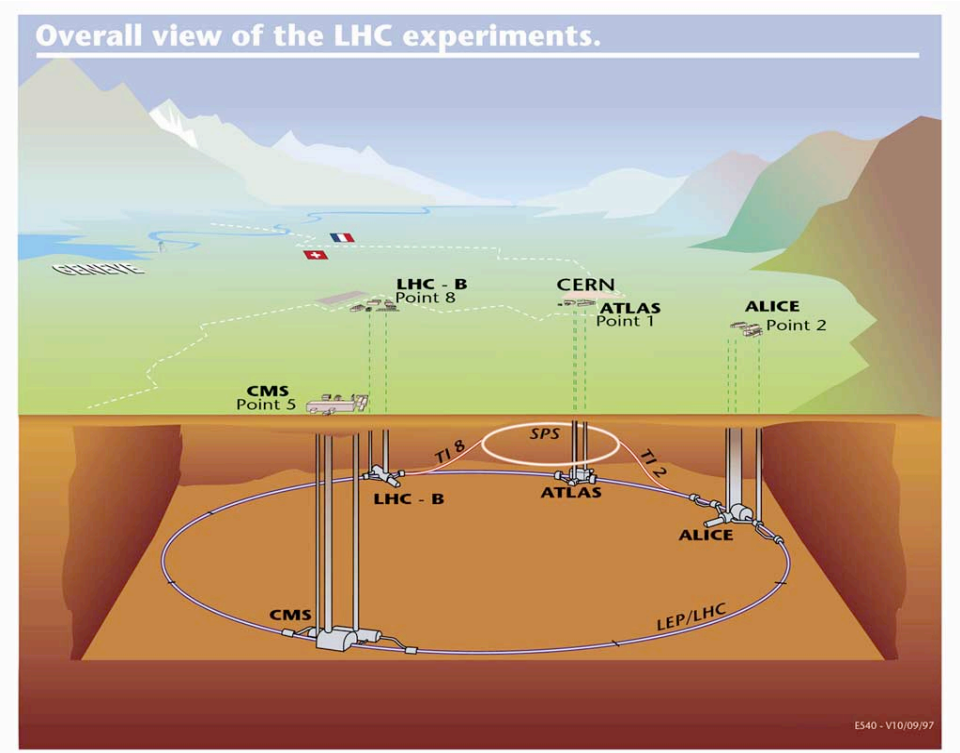
for the ATLAS and CMS collaborations

Outline

- LHC, ATLAS & CMS

- Supersymmetry at LHC
- ATLAS: search for $\tilde{g} \rightarrow \tilde{t} + \tilde{t}_1$
- CMS: inclusive search for $\tilde{t}_1 \rightarrow t + \chi_2^0$

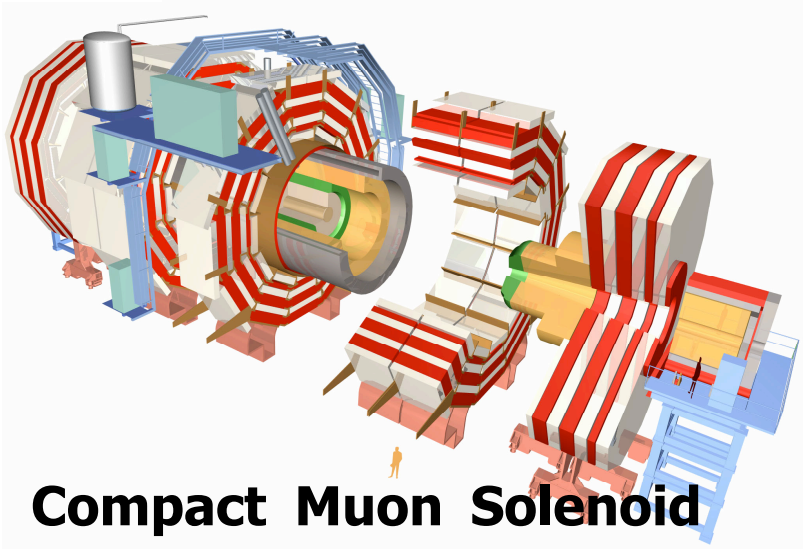


Large Hadron Collider

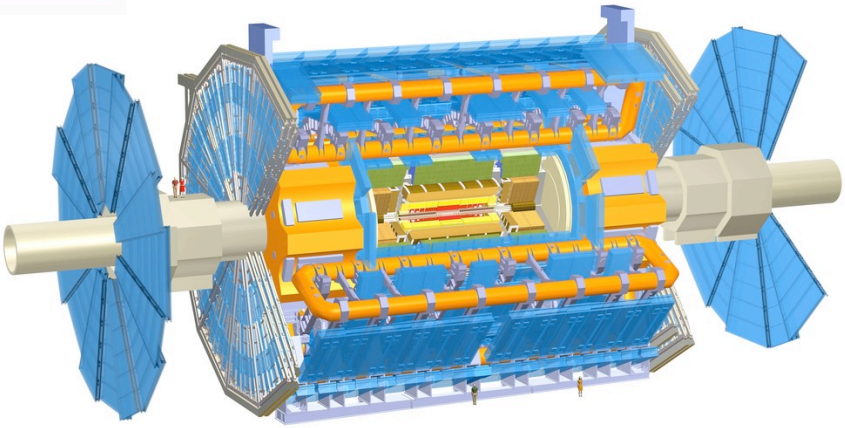
p-p collisions at $\sqrt{s} = 14$ TeV

First attempt at collisions:

July 2008



Compact Muon Solenoid



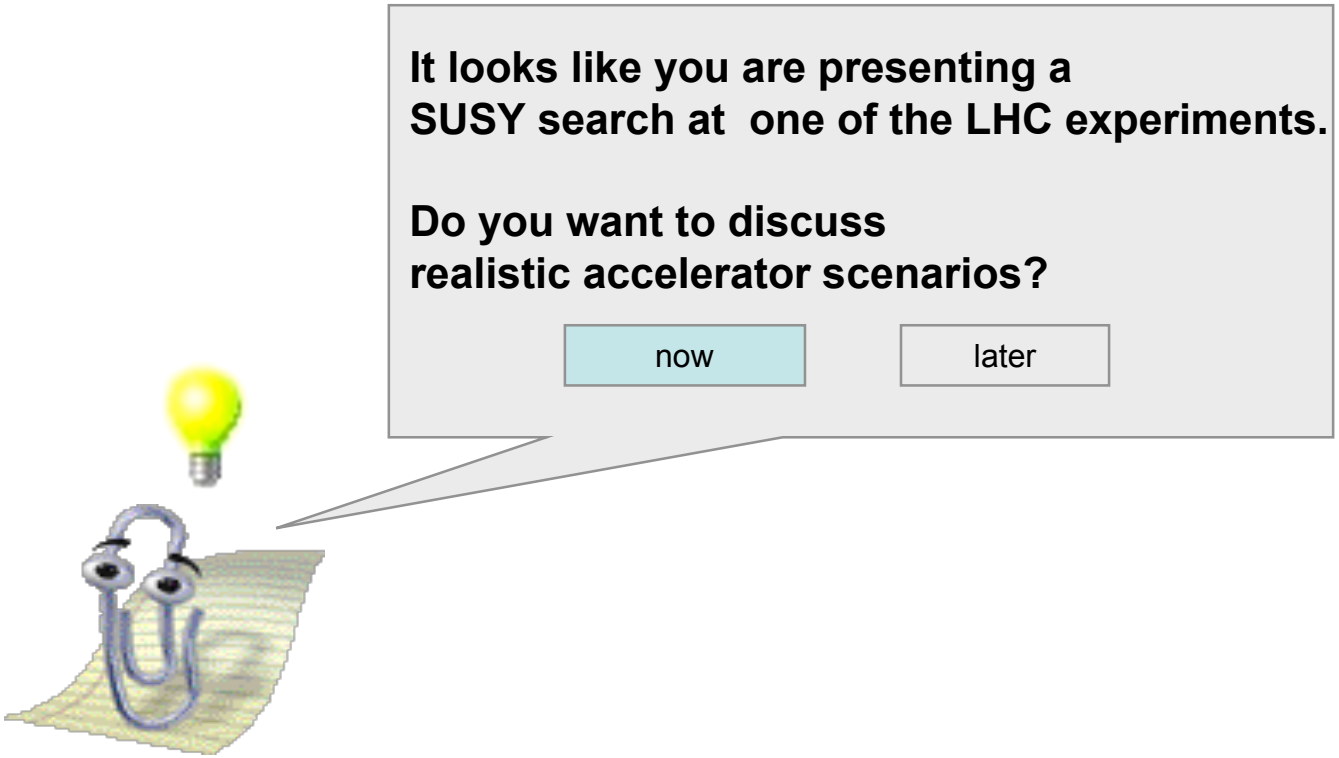
A Toroidal Lhc ApparatuS

Why Supersymmetry?

- Supersymmetric (SUSY) scenarios provide a very promising extension for the Standard Model (SM)
  - SUSY provides a possible dark matter candidate!
  - SUSY solves some Higgs instability problems
- SUSY is a broken symmetry
  - many flavours of symmetry breaking models available

Which SUSY breaking mechanism?

- Minimal Supergravity (mSUGRA)
  - Gravity responsible for (soft) SUSY breaking
  - Top quarks created by squark decay to top + neutralino ($\tilde{t_1} \rightarrow t + \chi_2^0$)
  - Increased cross sections
    - Tevatron limits currently around $\sigma(t_1) < 450$ pb
  - Look at two scenarios:
    - ATLAS: search early data for heavily increased signal
    - CMS: intermediate scenario, inclusive search
    - Both: Impossible to find 'mass' peak
      - R parity conserved: neutralinos in final state


It looks like you are presenting a
SUSY search at one of the LHC experiments.
Do you want to discuss
realistic accelerator scenarios?
now
later

What about LHC in 2008 ?

- Startup run:

  20 pb^{-1} at sqrt(s)=10 TeV

  – Analyses presented here:

    - Tuned for 200 pb^{-1} (ATLAS) or more (1 fb^{-1}, CMS)

ATLAS: Light stop search

Search for the gluino in the stop-top channel at ATLAS

SU4 low mass SUSY model:

Close to Tevatron Run II reach

σ^{LO}=294 pb (σ^{NLO}=402 pb)

sparticle masses in range 60-445 GeV

SU4 Parameters:

m_0=200 GeV, $m_{1/2}$=160 GeV, A_0=-400 GeV, tanβ=10, μ>0.

Monte Carlo:

Full simulation + PROSPINO 2.0.6

ATLAS: SU4 point phenomenology

SU4 masses and decays were obtained by ISASUGRA 7.71 where top mass of 175 GeV was used.

Mass range: $m(\tilde{\chi}_1^0) = 60$ GeV $< m <$ $m(\tilde{t}_2) = 445$ GeV.

Mass spectrum

Particle	Mass (GeV)	Particle	Mass (GeV)	Particle	Mass (GeV)	Particle	Mass (GeV)
$\tilde{\chi}_1^0$	60	$\tilde{q}_L$	412	$\tilde{e}_L,\tilde{\mu}_L$	232	h^0	114
$\tilde{\chi}_2^0,\tilde{\chi}_1^\pm$	113	$\tilde{q}_R$	405	$\tilde{e}_R,\tilde{\mu}_R$	213	H^0	370
$\tilde{\chi}_3^0$	309	$\tilde{t}_1$	206	$\tilde{\tau}_1$	200	A^0	368
$\tilde{\chi}_4^0,\tilde{\chi}_2^\pm$	326	$\tilde{t}_2$	445	$\tilde{\tau}_2$	236	$H^\pm$	379
$\tilde{g}$	413	$\tilde{b}_1$	358	$\tilde{\nu}_e,\tilde{\nu}_\mu$	212		
		$\tilde{b}_2$	400	$\tilde{\nu}_\tau$	216		

SU4 mass scale: $M_{SUSY} = \min(m(\tilde{g}), m(\tilde{q})) \sim 400$ GeV.

SU4 main decays

$\tilde{g} \to \tilde{b}_1 b$	47%	$\tilde{q}_L \to \tilde{\chi}_1^\pm q$	65%	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 q\bar{q}$	76%
$\tilde{g} \to \tilde{t}_1 t$	42%	$\tilde{q}_L \to \tilde{\chi}_2^0 q$	32%	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+l^-$	13%
$\tilde{g} \to \tilde{b}_2 b$	4%	$\tilde{q}_L \to \tilde{\chi}_1^0 q$	2%	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \nu_l \bar{\nu}_l$	10%
$\tilde{g} \to \tilde{q}_R q$	4%				
$\tilde{g} \to \tilde{\chi}_2^0 q\bar{q}$	2%	$\tilde{q}_R \to \tilde{\chi}_1^0 q$	98%	$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 qq$	65%
				$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 l \nu_l$	35%
$\tilde{t}_1 \to \tilde{\chi}_1^\pm b$	100%	$\tilde{b}_1 \to \tilde{t}_1 W$	46%		
		$\tilde{b}_1 \to \tilde{\chi}_2^0 b$	28%	$\tilde{\chi}_2^\pm \to \tilde{t}_1 b$	43%
$\tilde{t}_2 \to \tilde{t}_1 (Z^0/\gamma^\star)$	43%	$\tilde{b}_1 \to \tilde{\chi}_1^\pm t$	22%	$\tilde{\chi}_2^\pm \to \tilde{\chi}_2^0 W$	20%
$\tilde{t}_2 \to \tilde{\chi}_1^\pm b$	25%	$\tilde{b}_1 \to \tilde{\chi}_1^0 b$	4%	$\tilde{\chi}_2^\pm \to \tilde{\chi}_1^\pm (Z^0/\gamma^\star)$	16%
$\tilde{t}_2 \to \tilde{\chi}_2^\pm b$	13%	$\tilde{b}_2 \to \tilde{t}_1 W$	52%	$\tilde{\chi}_2^\pm \to \tilde{\chi}_1^\pm h^0$	11%
$\tilde{t}_2 \to \tilde{\chi}_2^0 t$	8%	$\tilde{b}_2 \to \tilde{\chi}_1^0 b$	27%	$\tilde{\chi}_2^\pm \to \tilde{\chi}_1^0 W$	3%
$\tilde{t}_2 \to \tilde{t}_1 h^0$	8%	$\tilde{b}_2 \to \tilde{\chi}_2^0 b$	9%	$\tilde{\chi}_2^\pm \to \tilde{\tau}_2 \nu_\tau$	2%
$\tilde{t}_2 \to \tilde{\chi}_1^0 t$	3%	$\tilde{b}_2 \to \tilde{\chi}_1^\pm t$	8%	$\tilde{\chi}_2^\pm \to \tilde{l}_L \nu_l$	3%

- 63% of SU4 events contain gluino
- BF($\tilde{g} \to t\tilde{t}$, $b\tilde{b}$)=93%
- m(stop) ≈ 30 GeV + M(top)
- m(gauginos) ≈ 30 GeV + M(W)
- Final states similar for both (s)top and gaugino/W
- 70% of events contains at least 2 b jets

ATLAS: Light stop signature

Light stop may be extracted from the gluino decay

$\tilde{g} \rightarrow \tilde{t}_1 t \rightarrow \tilde{\chi}_1^* tb$ BR=42% (= 18% of SU4 events produced with squark)

Def: kinematic endpoint of M (tb) system::

$$M^{max}(tb) = \left[m_t^2 + \frac{m_{\tilde{t}_1}^2 - m_{\tilde{\chi}_1^\pm}^2}{2m_{\tilde{t}_1}^2} \left((m_{\tilde{g}}^2 - m_{\tilde{t}_1}^2 - m_t^2) + \sqrt{(m_{\tilde{g}}^2 - (m_{\tilde{t}_1} - m_t)^2)(m_{\tilde{g}}^2 - (m_{\tilde{t}_1} + m_t)^2)} \right) \right]^{1/2}$$

Typical: $M^{max}(tb) \approx 300$ GeV.

Kinematically equivalent event topologies:

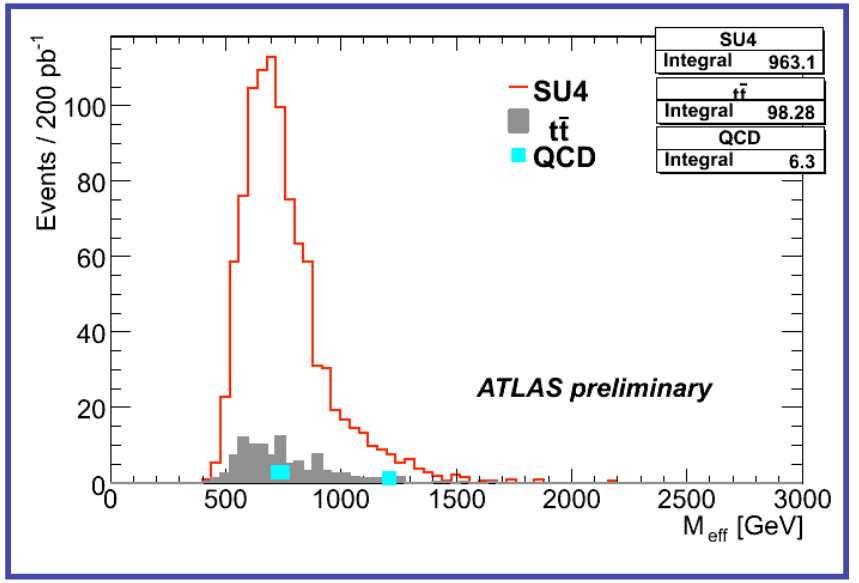
$\tilde{g}$	$\rightarrow$	$\tilde{b}_1 b \rightarrow \tilde{\chi}_1^\pm tb,$	4% of all SU4
$\tilde{g}$	$\rightarrow$	$\tilde{b}_1 b \rightarrow \tilde{t}_1 W b \rightarrow \tilde{\chi}_1^\pm bbW,$	9% of all SU4
$\tilde{g}$	$\rightarrow$	$\tilde{b}_2 b \rightarrow \tilde{\chi}_1^\pm tb,$	0.1% of all SU4
$\tilde{g}$	$\rightarrow$	$\tilde{b}_2 b \rightarrow \tilde{t}_1 W b \rightarrow \tilde{\chi}_1^\pm bbW.$	0.9% of all SU4

Suppress by cut on b-jet p_T.

ATLAS: Event Selection

Extraction stop signal from the gluino-squark SUSY background:

- **identify tops in hadronic decay**



Additional jets allowed:

$\tilde{\chi}_1^{\pm}$ decay to 2 additional *q* jets.

Squarks decay: most energetic jet in event typically from squark created with gluino

Event Selection:

- ✓ at least 5 jets with $p_T > 30$ GeV and $|\eta| < 2.5$
- ✓ the hardest jet is a light quark jet with $p_T > 100$ GeV,
- ✓ 2 and only 2 jets are tagged as b-jets with $p_T > 50$ GeV
  b-identification efficiency: 60 %
- ✓ $E_T^{miss} > 150$ GeV, $M_{eff} > 400$ GeV, $E_T^{miss} / M_{eff} > 0.2$ where
  $M_{eff} = E_T^{miss} + \Sigma p_T(j0,..,3) + \Sigma p_T(lepton)$
- ✓ Transverse sphericity $S_T > 0.1$.

ATLAS:M(tb) selection

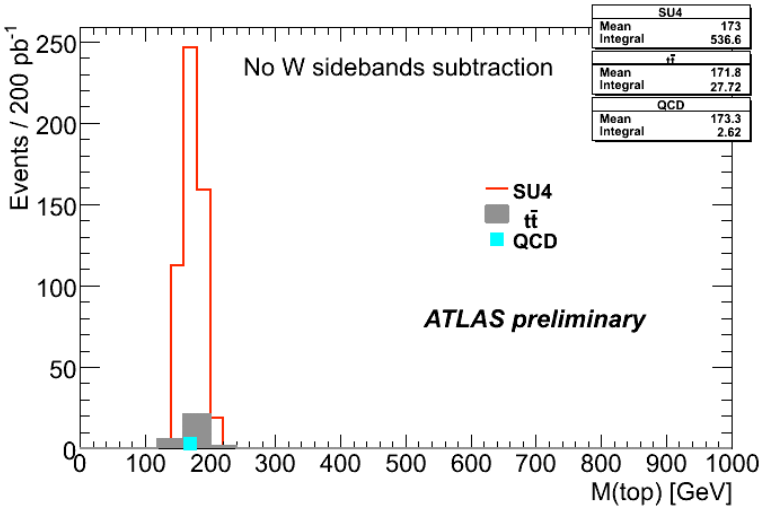
The top-bottom invariant mass is reconstructed for events satisfying selection criteria in the following way:

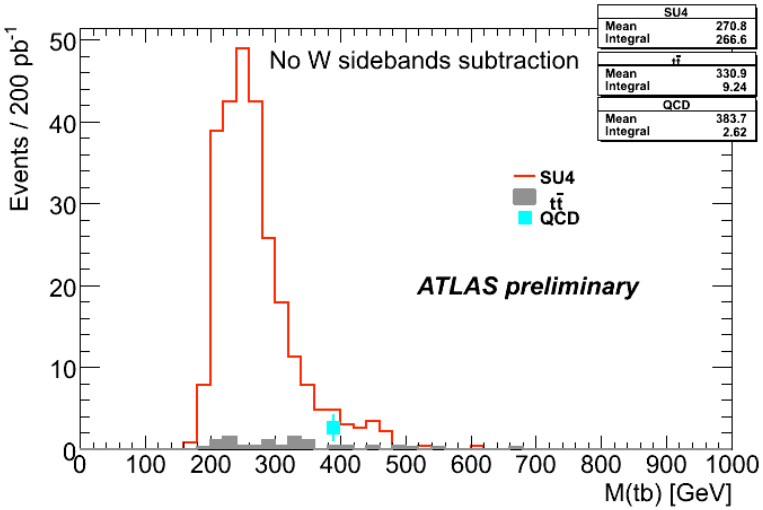
- ✓ Exclude the hardest jet
- ✓ other non-b jets are combined in jj pairs.
- ✓ Only consider jj pairs with $|M(jj)-m_W| < 15$ GeV for W candidate, use combination closest to m(top), force M(jj)=m_W and $|M(bjj)-m_{top}| < 30$ GeV
- ✓ Top candidate and other b-jet for $M(tb)$:

  require angle between top and bottom be $\Delta R<2$.

Backgrounds: only $t\bar{t}$ and QCD.

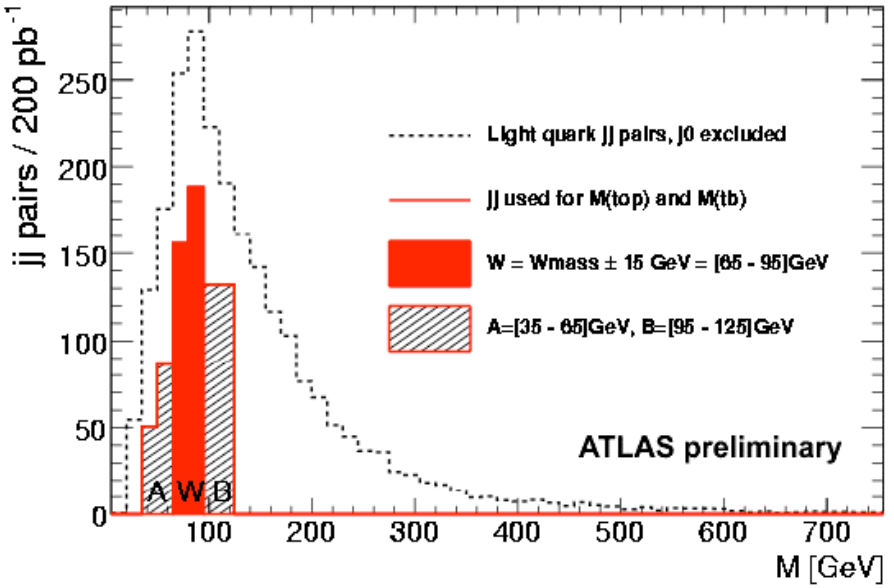
Considered backgrounds: W/Z + jets (negligible)

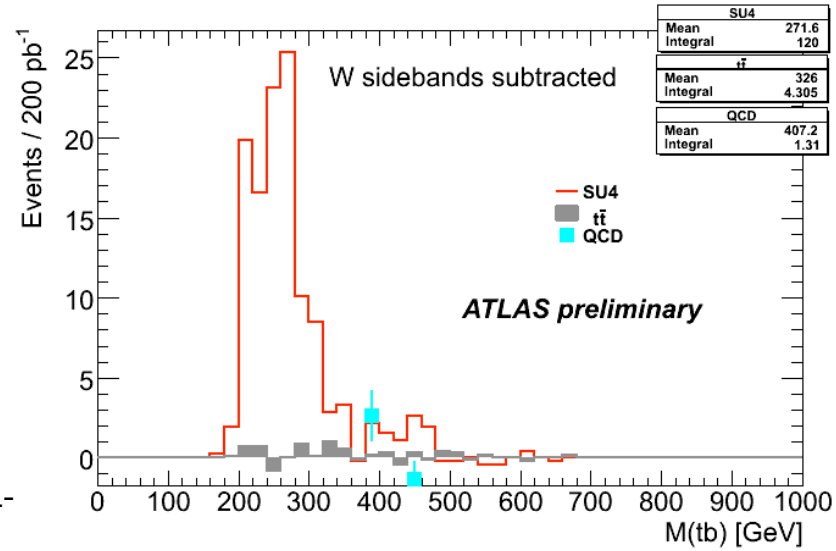




ATLAS: W sideband method

- ✓ The W sideband method is used to estimate SUSY combinatorial background originating from the super-symmetric processes where jet pairs accidentally have an invariant mass within the W mass zone ($m_W \pm$ 15 GeV)
- ✓ W sidebands A and B are mass regions 30 GeV bellow (A) and 30 GeV above (B) the W zone.
- ✓ Fake W bosons' contribution to *M(tb)* reconstruction is evaluated as the average contribution of the jet pairs from the W sidebands after they have been scaled linearly to the W mass zone and the procedure of *M(tb)* reconstruction had been repeated.





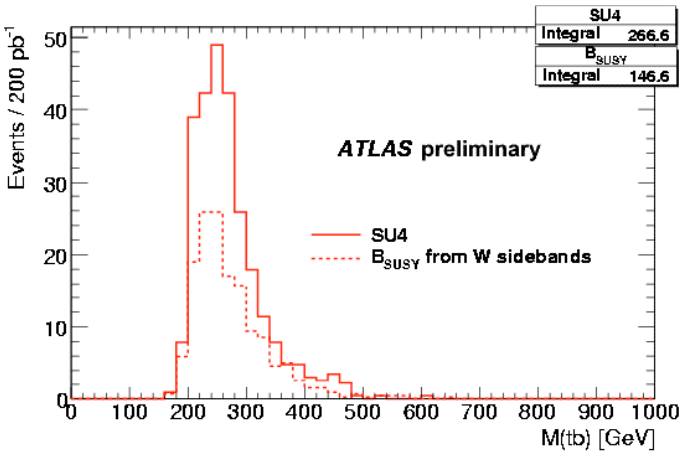
Method adapted from: J. Hisano, K. Kawagoe and M.M. Nojiri, ATL-PHYS-2003-29; ATLAS TDR, CERN-LHCC-99-01, Vol. 2, 845..

ATLAS: Results

Results for 200 pb^{-1}:

L = 200 pb^{-1}	Selection	$M(top)$		$M(tb)$	
		without W sub.	with W sub.	without W sub.	with W sub.
SU4	963	537	224	267	120
$t\bar{t}$	99	28	13	9	4
QCD	6	3	2	3	2
Event yield	1068 ± 426	568 ± 225	239 ± 95	279 ± 109	126 ± 50
SU4 / B_{SM}	9.2 ± 4.1	17.3 ± 7.3	14.9 ± 6.3	22.3 ± 9.1	20.0 ± 8.3

M(tb) in SU4 (without B_{SUSY} subtraction) and B_{SUSY}.

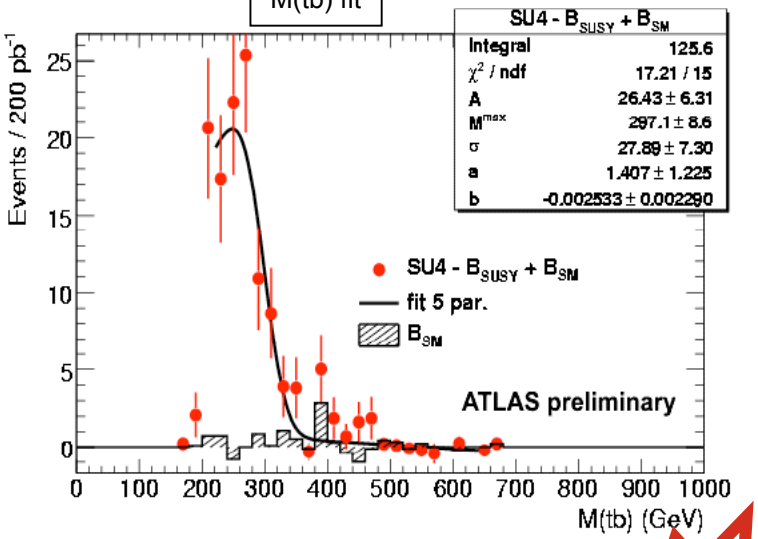


Fit background-subtracted M(tb) to extract the endpoint:

$$f(M) = A\int_{-1}^{1} e^{-\frac{(M-M^{max}\sqrt{\frac{1+x}{2}})^2}{2\sigma^2}}dx + (a+bM)$$

Triangular function smeared with the Gaussian.

M(tb) fit



The position of the upper kinematic endpoint obtained with the fit is M^{max} = 297 ± 9 GeV with smearing σ = 28 ± 7 GeV corresponding to ~ 10% of M^{max} value.

Input: 300 GeV

CMS: Inclusive stop search

- Event topology: top candidate + leptons + missing ET

$$\tilde{t_1} \rightarrow t + \chi_2^0 \rightarrow t + \tilde{l}_R + l \rightarrow t + l + l + \chi_1^0$$

- More than one top candidate ($t\bar{t}$) allowed
- Using CMS *LM1* mSUGRA scenario

m_0=60 GeV, $m_{1/2}$=250 GeV, A_0=0 GeV, tanβ=10, μ>0

CMS: LM1 point phenomenology

- Inclusive SUSY production

  LO (NLO): xsec = 42 pb (52 pb)

Inclusive SUSY top production

  LO (NLO): xsec = 6.8 pb (>9 pb)

LO generator: PYTHIA 6.225
NLO generator: PROSPINO

Sparticle	Mass(GeV/c^2)	Sparticle	Mass(GeV/c^2)
$\tilde{u_R}$,$\tilde{c_R}$	541.52	$\tilde{u_L}$,$\tilde{c_L}$	557.99
$\tilde{d_R}$,$\tilde{s_R}$	541.18	$\tilde{d_L}$,$\tilde{s_L}$	563.99
$\tilde{b_2}$	534.96	$\tilde{b_1}$	514.17
$\tilde{t_2}$	575.85	$\tilde{t_1}$	411.91
$\tilde{g}$	611.32	$\chi_2^{\pm}$	360.99
$\chi_1^{\pm}$	179.50	χ_4^0	361.81
χ_3^0	341.29	χ_2^0	179.56
χ_1^0	94.93	h_0	112.87

- Using K=1.24 (inclusive SUSY) for top enriched sample

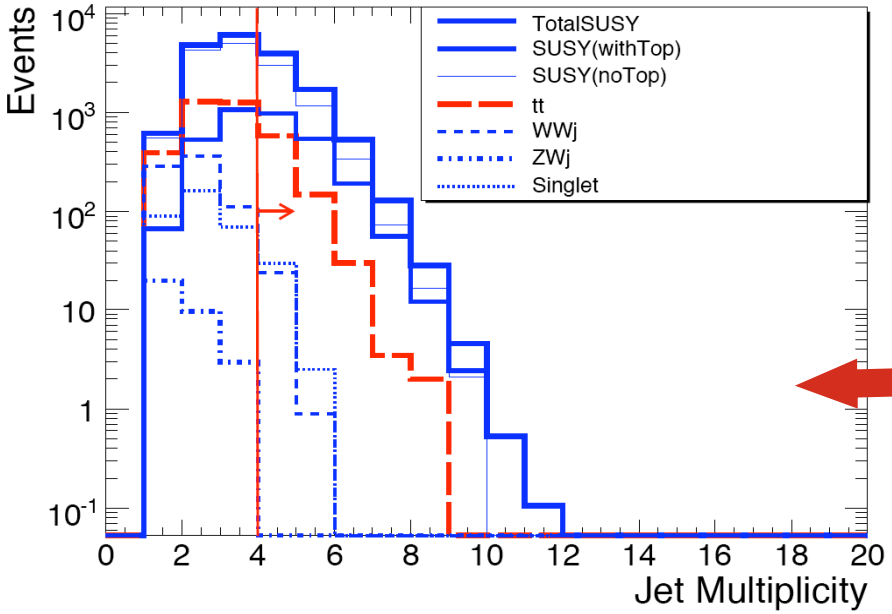
→ conservative limits

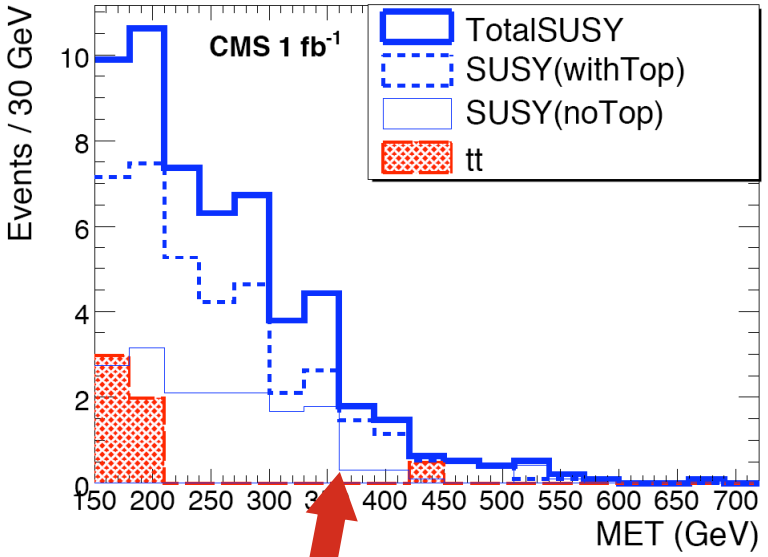
$Mother \rightarrow Daughters$	B.R(%)	$Mother \rightarrow Daughters$	B.R(%)
$\tilde{g} \rightarrow \bar{t} + \tilde{t_1}$	6.16	$\tilde{g} \rightarrow \bar{b} + \tilde{b_1}$	18.09
$\tilde{g} \rightarrow \bar{b} + \tilde{b_2}$	12.67	$\tilde{t_2} \rightarrow Z^0 + \tilde{t_1}$	12.17
$\tilde{t_2} \rightarrow h_0 + \tilde{t_1}$	2.62	$\tilde{b_2} \rightarrow W^- + \tilde{t_1}$	16.33
$\tilde{b_1} \rightarrow W^- + \tilde{t_1}$	6.64	$\tilde{t_1} \rightarrow \chi_2^0 + t$	12.53
$\tilde{t_1} \rightarrow \chi_1^0 + t$	17.70	$\tilde{t_2} \rightarrow \chi_{all}^0 + t$	40.58
$\tilde{b_1} \rightarrow \chi_1^+ + t$	48.36	$\tilde{b_2} \rightarrow \chi_1^+ + t$	23.85

CMS: Analysis strategy

Find number of expected top quark candidates in mSUGRA events for L = 1 fb^{-1}

Trigger:
L1: central jet > 88 GeV
missing ET > 46 GeV
HLT: central jet > 180 GeV
missing ET> 123 GeV

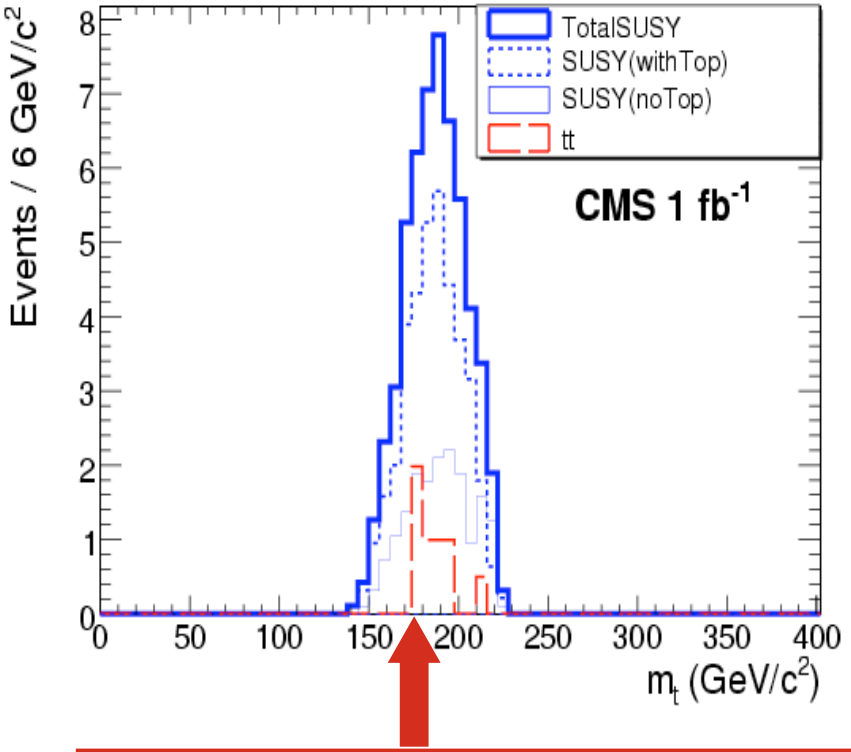




Preselection:
Missing ET > 150 GeV
N(jets) > 4

Jet = 0.5 cone algorithm, E_T > 30 GeV, $|\eta|$ <2.5
B-jet identification: Impact Parameter Track Count Tag

CMS: fit top mass



Combinatorial background

Constrained kinematic fit selects correct jet combination

Input:
- W mass
- top quark mass

Fit: χ^2 minimization
("partitioned matrix method")

Final event selection:
- Convergent fit with $P(\chi^2) > 0.1$
- $\Delta\phi$ between the fitted top and missing $E_T < 2.6$ rad
- One or more isolated lepton (e or μ) with $p_T > 5$ GeV/c and $|\eta| < 2.5$

CMS: Results

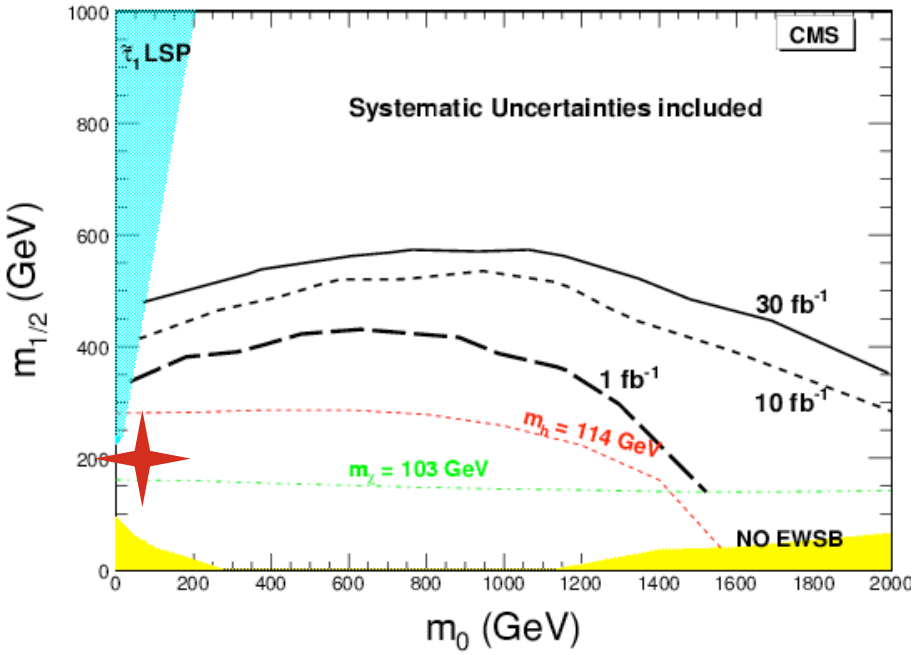
Analysis result, L=1 fb^{-1}:

Number of signal events :	38
Number of SUSY events (no top):	17
Signal Efficiency:	0.7 %
Standard Model background:	5 ± 21 % (syst)

All cuts were optimized by maximization of

$$2 \times (\sqrt{S+B} - \sqrt{B})$$

Discovery of mSUGRA stop production in CMS-LM1 scenario (✦):
Luminosity for 5-σ discovery is 0.2 fb^{-1} (including syst)



Shown: Results in mSUGRA parameter space (Fast Simulation)

Quick back-of-the-envelope calculation:

Results for 20 pb^{-1}

Typical mSUGRA xsec: 20 - 200 pb

xsec reduced by 50% at sqrt(s)=10 TeV

Practically no background

But also very low efficiencies:

ATLAS: Scale signal & background from 200 pb^{-1} by factor 20:

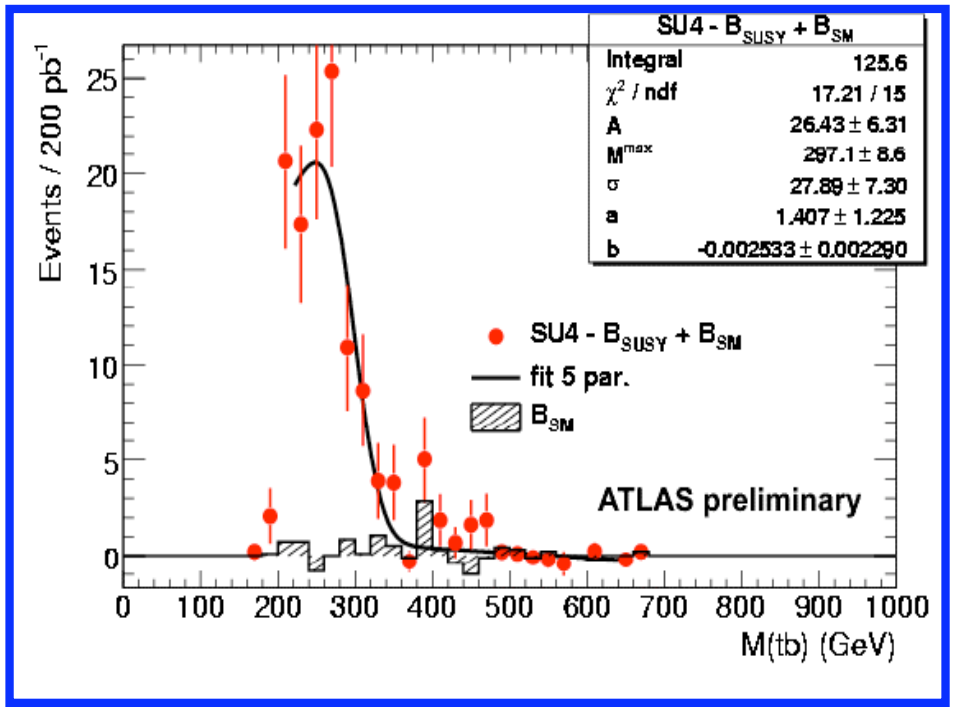
S= 537/20 B= 31/20

CMS: Scale signal & background from 1 fb^{-1} by factor 100:

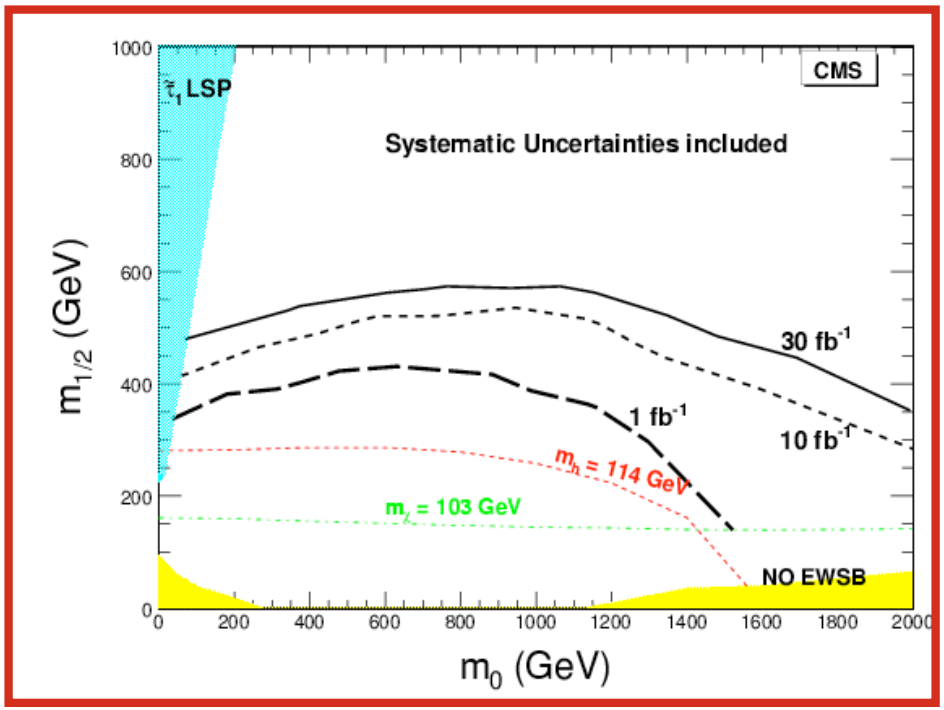
S= 55/100 B= 5/100 (eff=0.007 optimized on 1fb^{-1})

Conclusion

ATLAS CSC note 6, Section 7



CMS note AN2006-029 (and PTDR2)

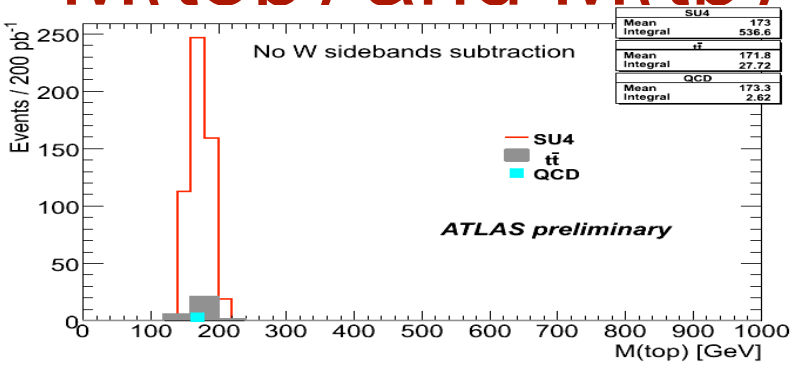


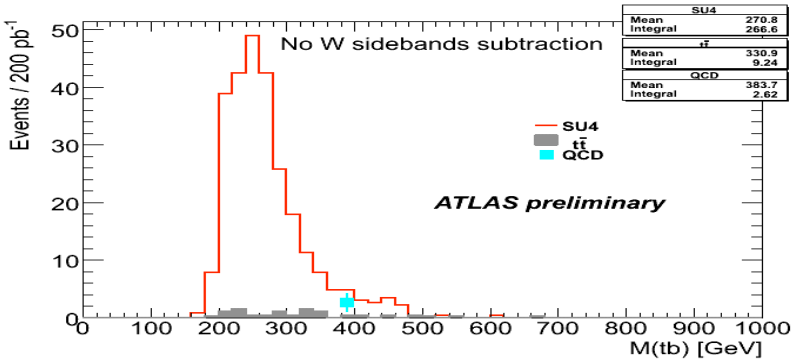
- ATLAS and CMS expect to be able to confirm or exclude stop quark production in mSUGRA scenarios after L = 0.2 fb^{-1}
- We are looking forward to the exiting times ahead!

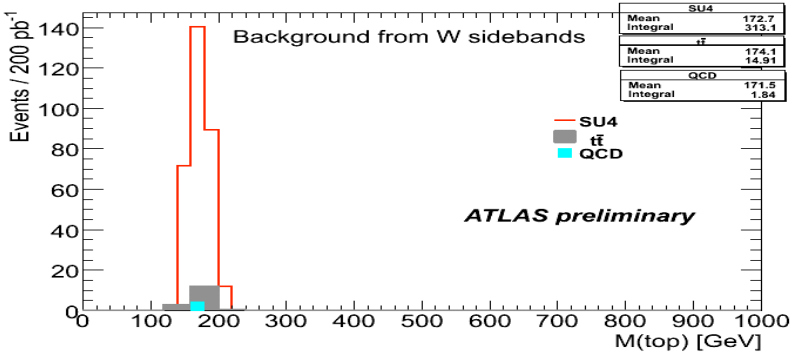
Backup slides

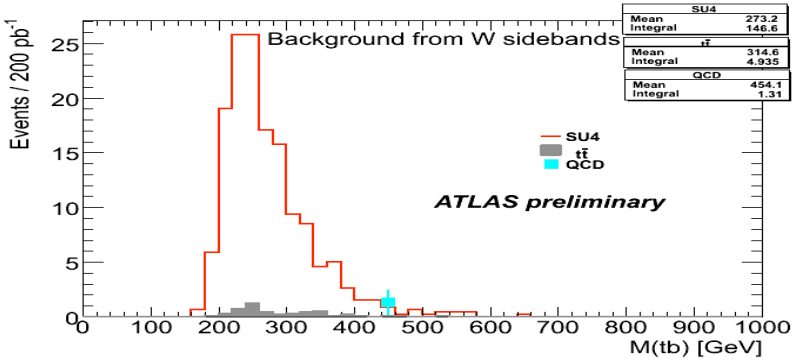
Cornell University

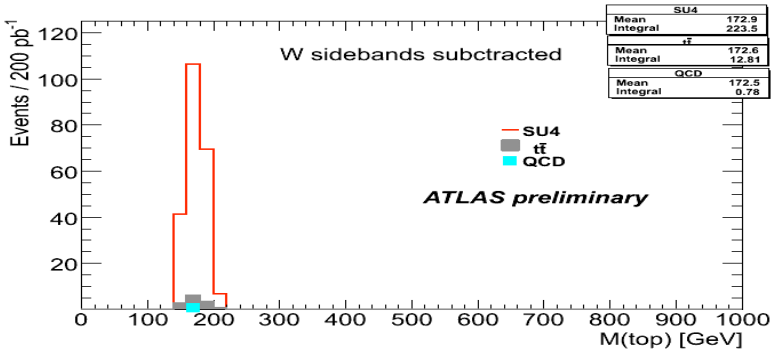
M(top) and M(tb) from W sidebands

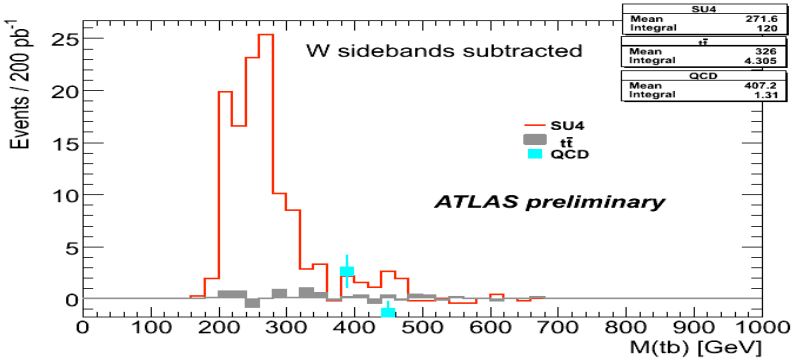












mSUGRA parameter explanation

- m_0 = common scalar mass
- $m_{1/2}$ = common gaugino mass
- A_0 = trilinear coupling strength
- tan(β) = ratio of expectation value of (2) higgs fields
- Sign(μ) = sign of higgsino mixing parameter

These 5 parameters are defined as free at the GUT scale.